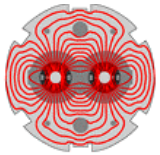


LARP

Development of TQ models based on 4-layer coils

Paolo Ferracin

LARP Collaboration Meeting

Port Jefferson

April 6 - 8, 2005

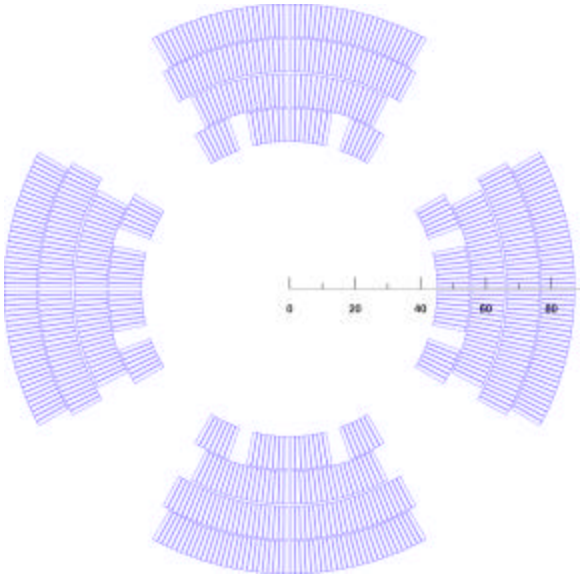
Outline

- Goals
- Design study
  - Magnet parameters
- Development steps and schedule
- Conclusions

Goals

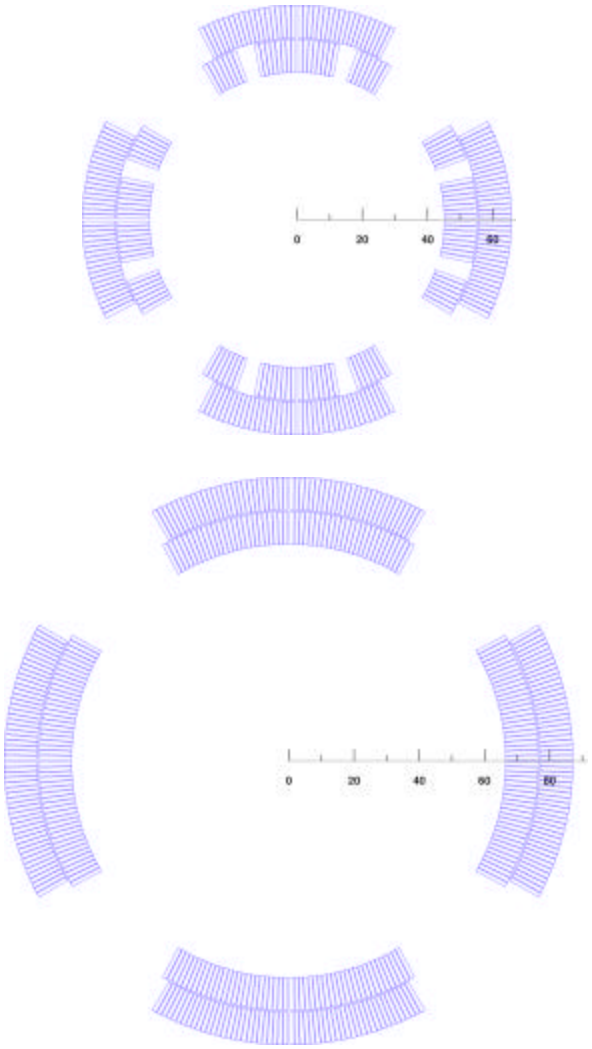
- Explore magnet design limits for an LHC luminosity upgrade
  - Gradient 300+ T/m (90 mm bore)
  - Peak field in the conductor 15+ T
  - Coil stresses 150+ MPa
  - Support structure

Four-layer design: magnet parameters



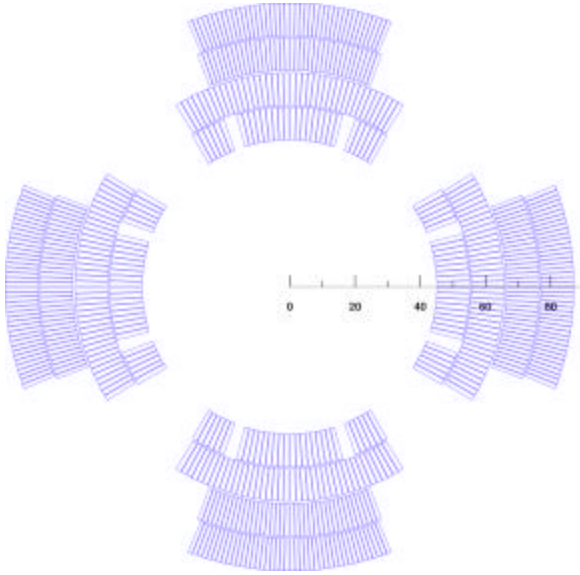
	Units	Inner	Outer
Strand diameter	mm	0.70	0.70
Cu/Sc		0.85	0.85
Cable width	mm	10.050	10.050
Cable thickness	mm	1.260	1.260
Keystone angle	deg	1.42	1.13
Insulation	mm	0.125	0.125
Turns		34	52
SC area	cm^2	28	43
J_c (12 T, 4.2 K)	A/mm^2	3000	3000
T_{op}	K	1.9	
J_{cu} @ I_{ss}	A/mm^2	2190	2190
G_{ss}	T/m	307	
I_{ss}	kA	10.5	
B_{peak}	T	15.6	15.6

Two-layer designs: magnet parameters



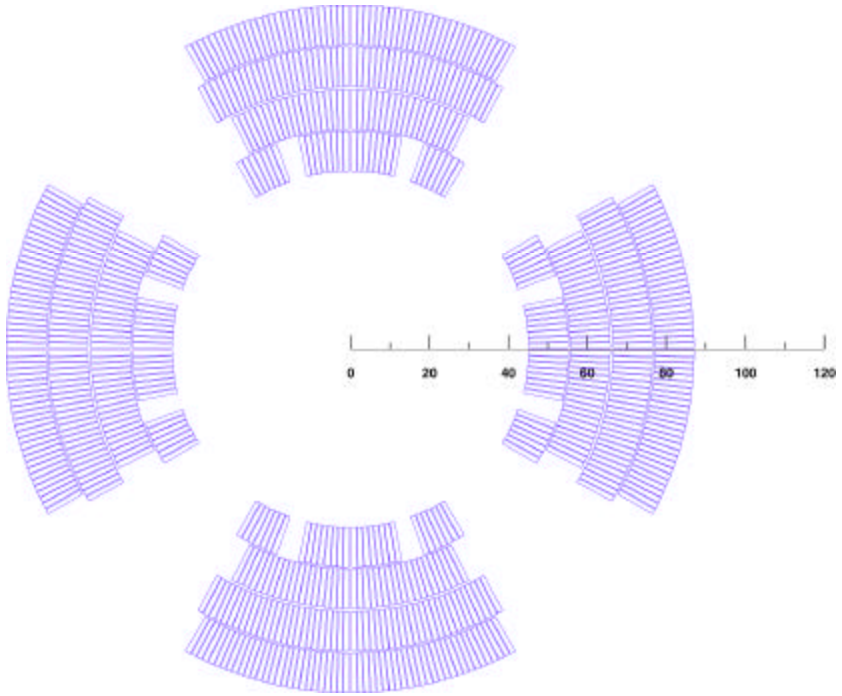
	Units	Inner	Outer
Strand diameter	mm	0.70	0.70
Cu/Sc		0.85	0.85
Cable width	mm	10.050	10.050
Cable thickness	mm	1.260	1.260
Keystone angle	deg	1.42	1.13
Insulation	mm	0.125	0.125
Turns		34	52
SC area	cm^2	28	43
J_c (12 T, 4.2 K)	A/mm^2	3000	3000
T_{op}	K	1.9	
$G_{ss\ (two\ layers)}$	T/m	257	187
$I_{ss\ (two\ layers)}$	kA	16.6	13.5
$B_{peak\ (two\ layers)}$	T	13.4	14.5

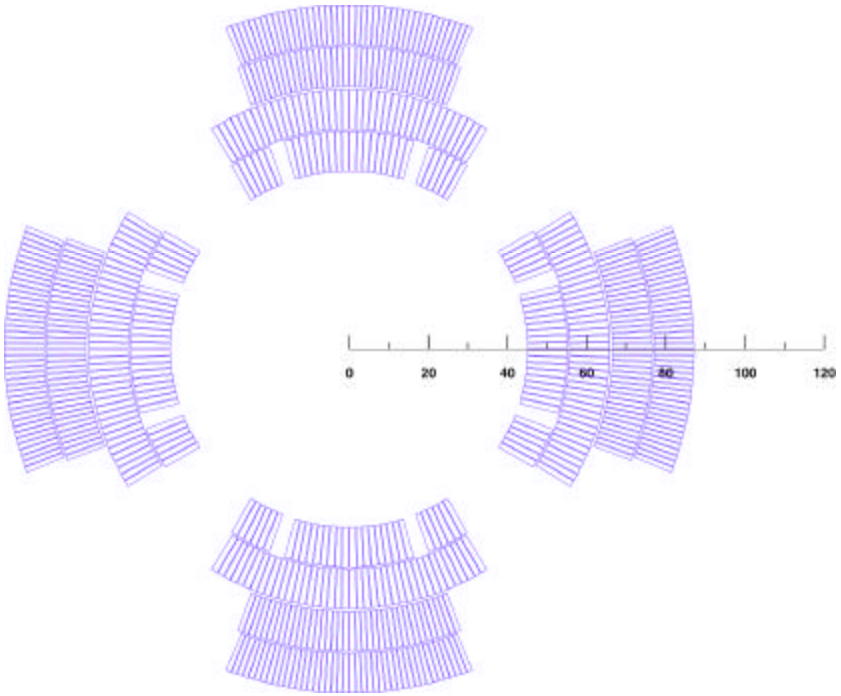
Four-layer design with grading: magnet parameters



	Units	Inner	Outer
Strand diameter	mm	0.80	0.65
Cu/Sc		0.85	1.30
Cable width	mm	10.050	10.050
Cable thickness	mm	1.440	1.170
Keystone angle	deg	1.60	1.08
Insulation	mm	0.125	0.125
Turns		35	40
SC area	cm^2	34	31
J_c (12 T, 4.2 K)	A/mm^2	3000	3000
T_{op}	K	1.9	
J_{cu} @ I_{ss}	A/mm^2	2090	2130
$G_{ss\ (four\ layers)}$	T/m	313	
$I_{ss\ (four\ layers)}$	kA	11.6	
$B_{peak\ (four\ layers)}$	T	15.9	13.6

Four-layer design: without and with grading



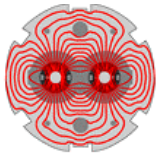


- Gradient: 307 T/m
- Peak field: 15.6 T
- SC area: 71 cm^2

- Gradient: 313 T/m
- Peak field: 15.9 T
- SC area: 65 cm^2

Development steps

1. TQ1b
   - Design, fabrication, assembly, and test of outer double-layer coil (130 mm aperture)
2. TQ4L-1
   - Assembly and test of TQ1b coil and TQ1a coil
3. TQ1c
   - Design, fabrication, assembly, and test of new inner double-layer coil
4. TQ4L-2
   - Assembly and test of TQ1c coil and TQ1b coil



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Step 1: TQ1b

TQ1b (outer double-layer)	FTE P/E	FTE D/T	Labor	M&S	M&S+G&A	Total
Design & Analysis						
Baseline design	0.10	0.00	$ 18,000			$ 18,000
Analysis & optimization	0.25	0.02	$ 48,000			$ 48,000
Assembly drawings	0.08	0.08	$ 26,400			$ 26,400
Tooling (Design, M&S and Ass'y)						$ -
Mandrel	0.02	0.05	$ 11,100	$ 17,594	$ 20,585	$ 31,685
Cavity	0.02	0.10	$ 18,600	$ 8,744	$ 10,230	$ 28,830
Reaction	0.04	0.10	$ 22,200	$ 18,000	$ 21,060	$ 43,260
Potting	0.02	0.10	$ 18,600	$ 3,600	$ 4,212	$ 22,812
Splice	0.02	0.10	$ 18,600	$ 1,728	$ 2,022	$ 20,622
Ground insulation fixture	0.02	0.05	$ 11,100	$ 5,040	$ 5,897	$ 16,997
Parts (design and procurement)						
Strand				$ 43,200	$ 50,544	$ 50,544
Insulation				$ 4,320	$ 5,054	$ 5,054
Coil (wedges, spacers)	0.02	0.17	$ 29,100	$ 46,080	$ 53,914	$ 83,014
Curing epoxy				$ 2,880	$ 3,370	$ 3,370
Splices	0.02	0.04	$ 9,600	$ 5,040	$ 5,897	$ 15,497
Ground insulation	0.02	0.03	$ 8,100	$ 2,880	$ 3,370	$ 11,470
Quench Heaters and traces	0.02	0.04	$ 9,600	$ 1,440	$ 1,685	$ 11,285
Impregnation epoxy				$ 7,200	$ 8,424	$ 8,424
Shell	0.01	0.02	$ 4,800	$ 11,520	$ 13,478	$ 18,278
Yoke	0.02	0.04	$ 9,600	$ 12,000	$ 14,040	$ 23,640
Pads/inserts	0.02	0.04	$ 9,600	$ 18,000	$ 21,060	$ 30,660
Z-rods, end plates	0.02	0.04	$ 9,600	$ 8,640	$ 10,109	$ 19,709
Bladders/keys	0.00	0.02	$ 3,000	$ 4,320	$ 5,054	$ 8,054
Instrumentation, drawings, connectors	0.10	0.10	$ 33,000	$ 2,880	$ 3,370	$ 36,370
Fabrication						
Cable fabrication	0.02	0.05	$ 11,100		$ -	$ 11,100
Cable cleaning and Insulation		0.05	$ 7,500		$ -	$ 7,500
Coil winding/curing	0.20	0.50	$ 111,000		$ -	$ 111,000
Mechanical model assembly/test/analysis	0.10	0.20	$ 48,000	$ 3,000	$ 3,510	$ 51,510
Reaction	0.04	0.25	$ 44,700		$ -	$ 44,700
Splicing, instrumentation	0.04	0.12	$ 25,200		$ -	$ 25,200
Potting	0.06	0.24	$ 46,800		$ -	$ 46,800
Sub-Assembly (pads)	0.01	0.02	$ 4,800		$ -	$ 4,800
Shell/yoke Assembly	0.01	0.02	$ 4,800		$ -	$ 4,800
Final Assembly (cold mass)	0.02	0.05	$ 11,100		$ -	$ 11,100
Electricals	0.01	0.02	$ 4,800		$ -	$ 4,800
Travelers/Procedures	0.08	0.16	$ 38,400		$ -	$ 38,400
Production reports	0.04	0.00	$ 7,200		$ -	$ 7,200
Assembly data analysis	0.08	0.00	$ 14,400		$ -	$ 14,400
Test						
Test preparations	0.10	0.10	$ 33,000		$ -	$ 33,000
Magnet test	0.10	0.20	$ 48,000	$ 20,000	$ 23,400	$ 71,400
Analysis and reporting	0.10	0.00	$ 18,000		$ -	$ 18,000
Total			$ 797,400		$ 290,284	**$ 1,087,684**

1,088 k$

Step 2: TQ4L-1

TQ4L-1	FTE P/E	FTE D/T	Labor	M&S	M&S+G&A	Total
Design & Analysis						
Baseline design			$ -			$ -
Analysis & optimization	0.15	0.02	$ 30,000			$ 30,000
Assembly drawings	0.05	0.08	$ 21,000			$ 21,000
Tooling (Design, M&S and Ass'y)						$ -
Mandrel			$ -		$ -	$ -
Cavity			$ -		$ -	$ -
Reaction			$ -		$ -	$ -
Potting			$ -		$ -	$ -
Splice			$ -		$ -	$ -
Ground insulation fixture			$ -		$ -	$ -
Parts (design and procurement)						
Strand					$ -	$ -
Insulation					$ -	$ -
Coil (wedges, spacers)			$ -		$ -	$ -
Curing epoxy					$ -	$ -
Splices	0.02	0.04	$ 9,600	$ 5,000	$ 5,850	$ 15,450
Ground insulation		0.02	$ 3,000	$ 3,400	$ 3,978	$ 6,978
Quench Heaters and traces			$ -		$ -	$ -
Impregnation epoxy					$ -	$ -
Shell			$ -		$ -	$ -
Yoke			$ -		$ -	$ -
Pads/inserts			$ -		$ -	$ -
Z-rods, end plates			$ -		$ -	$ -
Bladders/keys	0.00	0.02	$ 3,000	$ 4,000	$ 4,680	$ 7,680
Instrumentation, drawings, connectors	0.00	0.05	$ 7,500	$ 2,000	$ 2,340	$ 9,840
Fabrication						
Cable fabrication			$ -		$ -	$ -
Cable cleaning and Insulation			$ -		$ -	$ -
Coil winding/curing			$ -		$ -	$ -
Mechanical model assembly/test/analysis			$ -		$ -	$ -
Reaction			$ -		$ -	$ -
Splicing, instrumentation			$ -		$ -	$ -
Potting			$ -		$ -	$ -
Sub-Assembly (pads)	0.01	0.02	$ 4,800		$ -	$ 4,800
Shell/yoke Assembly	0.01	0.02	$ 4,800		$ -	$ 4,800
Final Assembly (cold mass)	0.02	0.05	$ 11,100		$ -	$ 11,100
Electricals	0.01	0.02	$ 4,800		$ -	$ 4,800
Travelers/Procedures	0.00	0.05	$ 7,500		$ -	$ 7,500
Production reports	0.04	0.00	$ 7,200		$ -	$ 7,200
Assembly data analysis	0.08	0.00	$ 14,400		$ -	$ 14,400
Test						
Test preparations	0.10	0.10	$ 33,000		$ -	$ 33,000
Magnet test	0.10	0.20	$ 48,000	$ 20,000	$ 23,400	$ 71,400
Analysis and reporting	0.10	0.00	$ 18,000		$ -	$ 18,000
Total			$ 227,700		$ 40,248	**$ 267,948**

268 k$

Step 2: TQ1c

TQ1c - new inner	FTE P/E	FTE D/T	Labor	M&S	M&S+G&A	Total
Design & Analysis						
Baseline design	0.05		$ 9,000			$ 9,000
Analysis & optimization	0.10	0.02	$ 21,000			$ 21,000
Assembly drawings			$ -			$ -
Tooling (Design, M&S and Ass'y)						$ -
Mandrel			$ -		$ -	$ -
Cavity			$ -		$ -	$ -
Reaction			$ -		$ -	$ -
Potting			$ -		$ -	$ -
Splice			$ -		$ -	$ -
Ground insulation fixture			$ -		$ -	$ -
Tooling modifications/optimization	0.02	0.05	$ 11,100	$ 5,000	$ 5,850	$ 16,950
Parts (design and procurement)						
Strand				$ 30,000	$ 35,100	$ 35,100
Insulation				$ 3,000	$ 3,510	$ 3,510
Coil (wedges, spacers)	0.02	0.15	$ 26,100	$ 32,000	$ 37,440	$ 63,540
Curing epoxy				$ 2,000	$ 2,340	$ 2,340
Splices			$ -	$ 3,500	$ 4,095	$ 4,095
Ground insulation		0.03	$ 4,500	$ 2,000	$ 2,340	$ 6,840
Quench Heaters and traces		0.04	$ 6,000	$ 1,000	$ 1,170	$ 7,170
Impregnation epoxy				$ 5,000	$ 5,850	$ 5,850
Shell			$ -		$ -	$ -
Yoke			$ -		$ -	$ -
Pads/inserts			$ -		$ -	$ -
Z-rods, end plates			$ -		$ -	$ -
Bladders/keys			$ -	$ 3,000	$ 3,510	$ 3,510
Instrumentation, drawings, connectors			$ -	$ 2,000	$ 2,340	$ 2,340
Fabrication						
Cable fabrication	0.02	0.05	$ 11,100		$ -	$ 11,100
Cable cleaning and Insulation		0.05	$ 7,500		$ -	$ 7,500
Coil winding/curing	0.10	0.40	$ 78,000		$ -	$ 78,000
Mechanical model assembly/test/analysis			$ -		$ -	$ -
Reaction	0.04	0.20	$ 37,200		$ -	$ 37,200
Splicing, instrumentation	0.04	0.12	$ 25,200		$ -	$ 25,200
Potting	0.06	0.24	$ 46,800		$ -	$ 46,800
Sub-Assembly (pads)	0.01	0.02	$ 4,800		$ -	$ 4,800
Shell/yoke Assembly	0.01	0.02	$ 4,800		$ -	$ 4,800
Final Assembly (cold mass)	0.02	0.05	$ 11,100		$ -	$ 11,100
Electricals	0.01	0.02	$ 4,800		$ -	$ 4,800
Travelers/Procedures	0.05	0.10	$ 24,000		$ -	$ 24,000
Production reports	0.04	0.00	$ 7,200		$ -	$ 7,200
Assembly data analysis	0.08	0.00	$ 14,400		$ -	$ 14,400
Test						
Test preparations	0.05	0.05	$ 16,500		$ -	$ 16,500
Magnet test	0.10	0.20	$ 48,000	$ 20,000	$ 23,400	$ 71,400
Analysis and reporting	0.10	0.00	$ 18,000		$ -	$ 18,000
Total			$ 437,100		$ 126,945	**$ 564,045**

564 k$

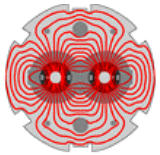
Step 4: TQ4L-2

TQ4L-2	FTE P/E	FTE D/T	Labor	M&S	M&S+G&A	Total
Design & Analysis						
Baseline design			$ -			$ -
Analysis & optimization	0.15	0.02	$ 30,000			$ 30,000
Assembly drawings	0.05	0.08	$ 21,000			$ 21,000
Tooling (Design, M&S and Ass'y)						$ -
Mandrel			$ -		$ -	$ -
Cavity			$ -		$ -	$ -
Reaction			$ -		$ -	$ -
Potting			$ -		$ -	$ -
Splice			$ -		$ -	$ -
Ground insulation fixture			$ -		$ -	$ -
Parts (design and procurement)						
Strand					$ -	$ -
Insulation					$ -	$ -
Coil (wedges, spacers)			$ -		$ -	$ -
Curing epoxy					$ -	$ -
Splices			$ -	$ 5,000	$ 5,850	$ 5,850
Ground insulation			$ -	$ 3,400	$ 3,978	$ 3,978
Quench Heaters and traces			$ -		$ -	$ -
Impregnation epoxy					$ -	$ -
Shell			$ -		$ -	$ -
Yoke			$ -		$ -	$ -
Pads/inserts			$ -		$ -	$ -
Z-rods, end plates			$ -		$ -	$ -
Bladders/keys	0.00	0.02	$ 3,000	$ 4,000	$ 4,680	$ 7,680
Instrumentation, drawings, connectors	0.00	0.05	$ 7,500	$ 2,000	$ 2,340	$ 9,840
Fabrication						
Cable fabrication			$ -		$ -	$ -
Cable cleaning and Insulation			$ -		$ -	$ -
Coil winding/curing			$ -		$ -	$ -
Mechanical model assembly/test/analysis			$ -		$ -	$ -
Reaction			$ -		$ -	$ -
Splicing, instrumentation			$ -		$ -	$ -
Potting			$ -		$ -	$ -
Sub-Assembly (pads)	0.01	0.02	$ 4,800		$ -	$ 4,800
Shell/yoke Assembly	0.01	0.02	$ 4,800		$ -	$ 4,800
Final Assembly (cold mass)	0.02	0.05	$ 11,100		$ -	$ 11,100
Electricals	0.01	0.02	$ 4,800		$ -	$ 4,800
Travelers/Procedures	0.00	0.05	$ 7,500		$ -	$ 7,500
Production reports	0.04	0.00	$ 7,200		$ -	$ 7,200
Assembly data analysis	0.08	0.00	$ 14,400		$ -	$ 14,400
Test						
Test preparations	0.10	0.10	$ 33,000		$ -	$ 33,000
Magnet test	0.10	0.20	$ 48,000	$ 20,000	$ 23,400	$ 71,400
Analysis and reporting	0.10	0.00	$ 18,000		$ -	$ 18,000
Total			$ 215,100		$ 40,248	**$ 255,348**

255 k$

Schedule

	FY06				FY07			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TQ1b	Design							
		Fab. outer double layer tooling and structure		Fab. TQ1b coil	Ass./ test TQ1b			
TQ4L-2						Ass./ test TQ1a + TQ1b		
TQ1c					Fab. TQ1c coil		Ass./ test TQ1c	
TQ4L-2								Ass./ test TQ1c + TQ1b



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Conclusions

- A four-layer design addresses the stated LARP goals
- Gradient above 300 T/m (90 mm bore)
- Peak field close to 16 T
- Magnet developed with intermediate steps
  - More flexibility and lower risk
  - Outer layer with 130 mm aperture and 14.5 T peak field